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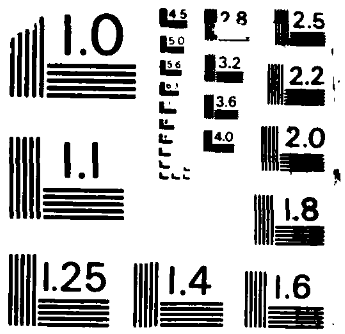

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AD-A190 494

ECP–A Proposed Program for Electrical Circuitry Analysis

by
Cynthia K. Barton
Anthony J. Williams

This research analyzed and proposed development of the computerized Electrical Circuitry Program (ECP). ECP is proposed to assist U.S. Army Corps of Engineers (USACE) in-house electrical engineers in performing the required analysis during facilities concept design phase.

The program would include features which allow the user to design a thorough power system with minimum effort. The program would also allow the user to graphically determine outlet locations for luminaries, establish receptacle locations and types, select switch locations and types, lay out wiring diagrams for the system, and locate and describe the features of the panelboards. ECP would be equipped to perform voltage drop, short circuit, and wire length calculations to insure the system design's efficiency. Using the information entered into the program, ECP would create summary reports and panel schedules to be submitted with design documents.

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FOREWORD

This work was performed for the Directorate of Engineering and Construction, Headquarters, U.S. Army Corps of Engineers (HQUSACE), under Project 4A162781AT45, "Energy and Energy Conservation"; Technical Area A, "New Construction Energy Design"; Work Unit 011, "Computer-Aided Mechanical/Electrical Design and Procedures." J. McCarty, CEEC-EE, was the HQUSACE Technical Monitor.

The work was conducted by the Energy Systems (ES) Division, U.S. Army Construction Engineering Research Laboratory (USA-CERL). Dr. G. R. Williamson is Chief, USA-CERL-ES. The Technical Editor was Gloria J. Wienke, Information Management Office.

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COL Norman C. Hintz is Commander and Director of USA-CERL, and Dr. L. R. Shaffer is Technical Director.

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ECP—A PROPOSED PROGRAM FOR ELECTRICAL CIRCUITRY ANALYSIS

1 INTRODUCTION

Background

During the concept design phase of a building, architects and engineers must analyze several design options and select one that optimizes cost and functionality. U.S. Army Construction Engineering Research Laboratory (USA-CERL) researchers have developed a set of interdisciplinary programs which encompasses nearly every aspect of the design phase: building layout, site layout, heating, ventilation, and air-conditioning layout and analysis, and lighting layout and analysis. In most cases, the engineers strive for design solutions that also conform to energy-efficient concepts. The amount of data to be considered and the complexity of the calculations have made it desirable to create automated programs which can help improve the potential for high-quality construction.

During the concept design phase, electrical engineers must create the lighting design and define portions of the electrical circuitry layout. Researchers at USA-CERL discovered that few commercial programs in existence today will perform the required calculations and produce a graphical representation of the system in one package. No previously developed program in USA-CERL's set of interdisciplinary programs could meet these requirements. The Electrical Circuitry Program (ECP) is being proposed to fill this gap.

The U.S. Department of Defense (DOD) requires[1] that all power systems within buildings and facilities shall be in accordance with the applicable National Fire Protection Association (NFPA) Codes, which are known as the National Electrical Code (NEC).[2] The Army has published Technical Manuals (TMs) to be followed by electrical engineers when designing power systems. For example, TM 5-811-1/AFM 88-9 Chapter 1,[3] gives detailed descriptions of design criteria for every facet of power systems design. The NEC is used as a basis for electrical system design and is referenced by all electrical engineers. The ECP module is being designed to conform to the required guidelines set forth for the concept design phase in all these documents.

Engineers have to consider energy efficiency needs when designing power systems. Presently, there are no criteria to determine the efficiency of a power system design. Inefficient energy use in electrical systems is typically the result of unnecessary (extensive) wiring, undersized transformers, and short circuits in the system. Because the calculations are often tedious, circuitry analysis is a good candidate for computerization. Using a computerized design and analysis program, with its iterative capabilities, could help prevent inaccurate solutions which lead to surplus energy use. It is anticipated that DOD directives will include a requirement for considering the most cost-effective energy conservation measures while determining electrical power and distribution requirements

[1] DOD 4270.1-M, *Construction Criteria Manual* (DOD, 1983).
[2] *National Electrical Code 1987* (National Fire Protection Association, 1987).
[3] Technical Manual 5-811-1/Air Force Manual (AFM) 88-9 Chapter 1, *Electrical Power Supply and Distribution* (Headquarters, U.S. Department of the Army, September 1984).

for new commercial buildings. A draft of proposed subpart A to Part 435, Chapter II of Title 10, Code of Federal Regulations (CFR), outlines measures to be applied in both design and post-occupancy situations.[4]

Objective

The objective of this research is to analyze and propose development of a graphic electrical circuitry program, ECP. ECP is proposed to help USACE electrical engineers perform the required analysis during facilities' concept design phase. The program is intended for use during the first 35 percent of the design phase.

Approach

Existing programs were reviewed to identify prescriptive standards and techniques relating to electrical circuitry design and analysis. Data required in each of the programs were analyzed for commonality.

USA-CERL researchers interviewed members of the USACE Kansas City and Sacramento District Electrical Branches to acquire an understanding of the USACE requirements in electrical circuitry design. The ECP module was then outlined to conform to current USA-CERL computing standards and address the issues faced by electrical engineers while designing Military Construction, Army (MCA) facilities.

Mode of Technology Transfer

ECP is proposed to be written and tested in-house during the next fiscal year. The program will then undergo formal field-testing as prescribed by current Technology Transfer Test Bed (TTTB) procedures. After refinement, an Engineering Improvement Recommendation System (EIRS) Bulletin will be prepared and ECP will be transferred to the field via training courses with hands-on experience, tutorial, and a user's manual. The program will be made available on Harris Corporation computers which are available in most Corps District and Division Offices. A version of this program will also be for proposed conversion to use on microcomputers. In addition, ECP may also be converted to workstations procured under the U.S. Army Corps of Engineers/Intergraph central computer-aided design and drafting (CADD) contract.

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[4] *Federal Register*, "Notice of Proposed Rulemaking," Vol 52, No. 87 (May 6, 1987).

2 ORGANIZATION OF ECP

Current Design Procedures

During the investigation of electrical power systems design, USA-CERL researchers noted that few programs give a comprehensive overview of the total design procedure. The researchers contacted several USACE District Office electrical engineers in early FY87 to compile a comprehensive list of design methods and computer programs used throughout the Corps. Most of the design methods were completed manually with the help of PC-based computer programs for calculations used in power system analysis. The Appendix contains a short description of each program used as background to develop the criteria for ECP. The descriptions include calculation methods, if applicable, or explanations about the rationale of the graphics design in the graphics programs.

The computer programs used by USACE engineers can be broken into two categories: those that are primarily for performing calculations, and those that are graphics programs pertaining to power systems design. When possible, the programs were reviewed using demonstration disks offered by the manufacturer. Programs that required hardware not accessible to the USA-CERL researchers were reviewed through documentation only.

ECP is designed to encompass both the major calculation features and graphics capabilities of all the programs reviewed and to give the electrical engineer a more concise method of constructing an electrical power system during the concept phase. Presently, the electrical engineers follow the guidelines set by DOD, but follow their own individual decisions concerning the actual use or application of the guidelines in USACE projects. With ECP as an extra guideline, the electrical engineer will be able to place greater emphasis on energy use in the power system. This process will also enable the engineer to build a more concise foundation for project development. Although ECP is still in the design stage, this chapter will discuss the proposed elements as if the program had already been written and is ready for testing.

ECP cannot be used as a stand-alone program. During the design process, the engineer will begin by creating the building layout using the ARCH program.[5] In initiating ECP, the building layout is retrieved from the ARCH data file and displayed on the screen with the menu. The engineer should also create the reflected ceiling plan using the LITE program[6] before executing ECP, as the luminaire locations need to be included in the power system. A user who is familiar with ARCH and LITE, should be able to use ECP with little difficulty after a brief demonstration. The LITE User's Manual and the ARCH User's Manual should be consulted by the beginning user before attempting to execute ECP. The interaction between ECP and LITE is further discussed in Chapter 3.

Information Exchange

The designer gives the ECP instructions by issuing commands at an interactive graphics terminal. The terminal must be a Tektronix 4010 or 4100 series graphics terminal, or one which can emulate these. The instructions to ECP are entered in two

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[5]C. Barton, *Arch User's Manual*, Draft Automated Data Processing (ADP) Report (U.S. Army Construction Engineering Research Laboratory [USA-CERL], 1986).
[6]C. Barton, *Lite User's Manual*, Draft ADP Report (USA-CERL, 1986).

modes: typing a response followed by a carriage return (<cr>), or positioning "the crosshairs" over a specific area of the screen and typing a single key. In "the crosshairs" input mode, the ECP will determine the actual X, Y coordinates of the crosshairs intersection, as well as the key that was typed.

Depending upon the type of input, ECP will communicate with the user by an appropriate display or alphanumeric prompt. If ECP does not understand a command or if a command is not correctly issued, the program will issue appropriate diagnostics.

The Screen Display

The screen is divided into two physical areas: the Text Area and the Graphical Input Area. All written prompts and diagnostics from ECP and all responses typed by the user appear in the text area. Whenever the user enters text in response to a prompt, it must be followed by a carriage return. The Graphical Input Area is where all crosshair positioning and single key commands are used. The Graphical Input Area is further divided into two areas, the Menu Area and the Layout Area, as shown in Figure 1. The Menu Area allows the user to select the type of action to be performed by the program. Each action, called a mode, has a subset of commands which are unique to that mode only. When operating within a mode, only that mode's subset of commands may be issued. The Layout Area is where the circuitry design is laid out over the ARCH and LITE models of the building.

Project Names and Files

ECP uses much of the information entered through ARCH (e.g., room dimensions and room labels), plus luminaire information from LITE, and creates its own data file which is stored on the computer disk. The project name is used to generate the disk file and, therefore, must be unique. During an ECP session, changes to a project are not stored on the project's data file until the user gives an explicit request to save the project.

Building the ECP Data Base

ECP breaks down the circuitry design process into smaller sets of related actions called modes. To access a mode, the crosshairs are placed over the desired mode in the menu area, and any alphanumeric key is pressed. The user may then continue to work within that mode until another mode is selected. Each menu command name describes, in one or two words, a subset of the design process which may be completed within that mode. For example, the RECEPTCL mode allows the user to describe receptacle types and locations. Figure 2 shows the ECP menu modes and their commands. The following paragraphs briefly explain the functions of each of the ECP modes.

MENU COMMAND Mode

The MENU COMMAND mode is an intermediate step between the other modes. ECP starts in this neutral position when the user first accesses the program.

IDENTIFY LUMINAIR Mode

In the IDENTIFY LUMINAIR mode, the user locates outlets to be used in the lighting system. The reflected ceiling plan that was originally designed in the LITE program, can be retrieved and displayed on the screen as a reference during this mode. The luminaire outlets are symbolized by a small circle, which can be designated anywhere inside the luminaire device symbol. By default it will be the centroid of the luminaire location. The user is also given the option of adding or deleting, individually or project wide, the outlet symbols.

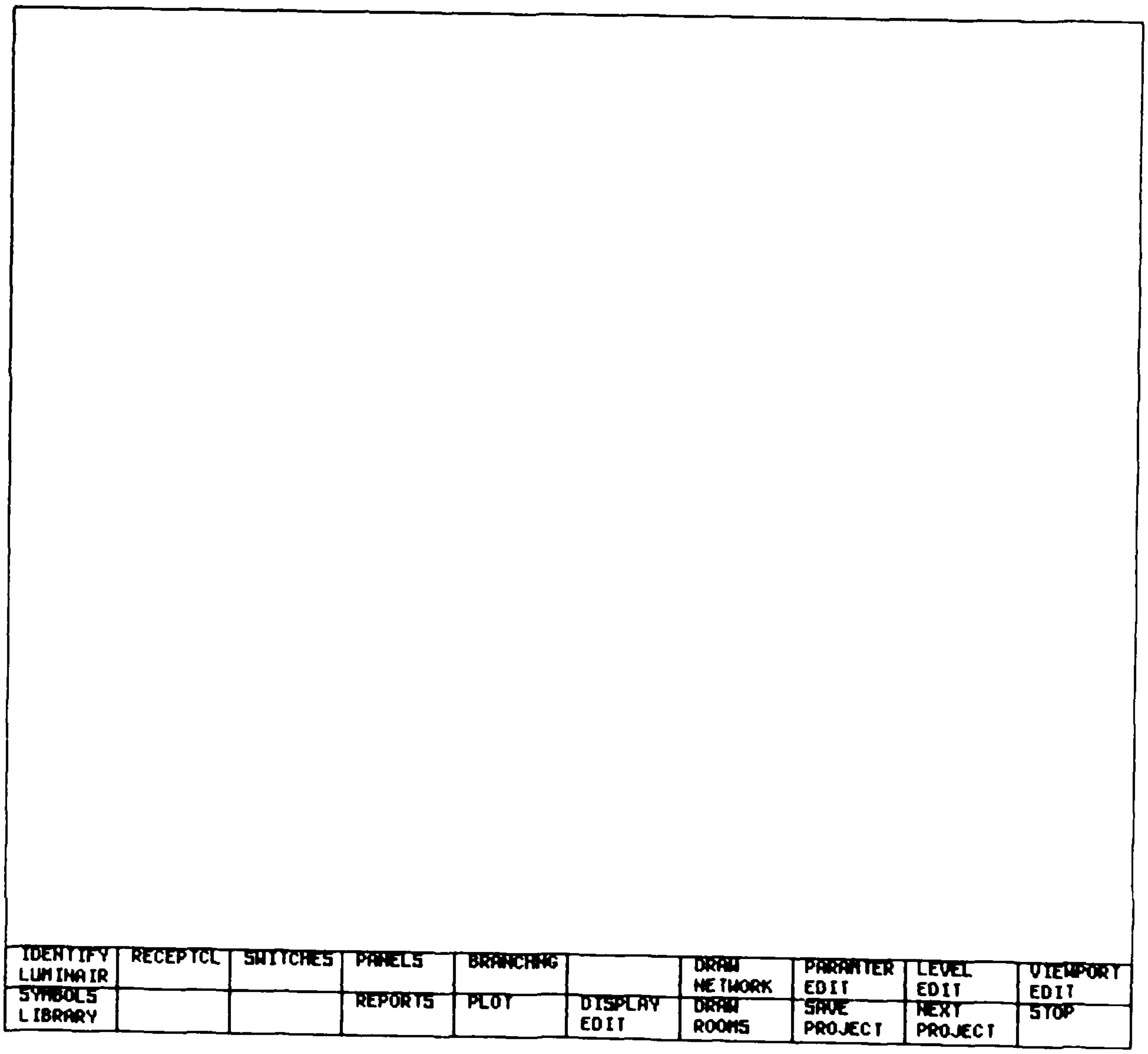

Figure 1. The graphical input area.

IDENTIFY LUMINAIR

L - List Commands

S - Show Reflected Ceiling Plan
A - Add Outlets
G - Add Outlets by Group
D - Delete Outlets
E - Delete Outlets by Project

RECEPTCL

L - List Commands

A - Add Receptacles
D - Delete Receptacles
C - Change Receptacle Position
N - Change Receptacle Type
T - Change Receptacle Data

P - Print List of Receptacles
S - Show Receptacle Information

SWITCHES

L - List Commands

A - Add Switch
D - Delete Switch
C - Change Switch Type
N - Change Switch Data

P - Print List of Switches
S - Show Switch Information

BRANCHING

L - List Commands

C - Create Element Series
E - Delete Series
A - Add Element to Series
D - Delete Element from Series
S - Show Series Information

P - Combine Series
W - Change Wire Type
F - Default Wire Type

PANELS

L - List Commands

A - Add Panel
D - Delete Panel
C - Change Panel Characteristics

G - Assign Circuits
H - Change Circuit Charactersitics
S - Show Panel Information
V - Voltage Drop Calculations
T - Short Circuit Calculations
M - Add Wire Length Per Series
Y - Total Wire Length for Project

REPORTS

L - List Commands

P - Panel Schedule
C - Circuit Summary Report
Z - Circuit Summary Print Options
  Switch (Yes)
  Receptacle (Yes)
  Panels (Yes)
  Branching (No)
S - Luminaire Summary Report

Figure 2. Menu command modes.

RECEPTACL Mode

Another part of the power system that must be shown in concept design documents are the receptacles, which are described in the RECEPTCL mode. In this mode, the user can add, delete, change the position of, and change the type of receptacles (both individual and project wide) used in a particular project. The program will also show the specific information pertaining to the receptacles already placed on the floor plan. The receptacle types commonly used in electrical systems design will be kept in a "library" which can be accessed by the user during any project. If a receptacle device is not included in the database, it can be added and will be stored in the receptacle database for the project it was stored under. See the SYMBOLS LIBRARY mode later in this chapter for a further discussion of the symbols library.

SWITCHES Mode

In a power system, the switches are a necessary part of the lighting design. In the SWITCHES mode, the electrical engineer can add or delete switches and change the type of switch, either project wide or by individual switch. The user can also print a list of switch types for the project and show switch information pertaining to the switches already placed on the drawing.

BRANCHING Mode

In the BRANCHING mode, the user can wire and connect the system. There are two primary phases in the BRANCHING mode: the creation and layout of the circuitry system, and the wiring description. The creation and layout of the electrical system consists of designing and connecting the various devices included in the circuits. The devices, such as receptacles, outlets, and switches, are described as "elements" by the program. A "series" is considered a collection of elements (i.e. four lights and the switch that controls them). A collection of series (or a large single series) make up a "circuit." Thus, a circuit is considered the wiring layout (elements included) from the home run point to the final element being supplied with electricity. The home run point is designated on the circuit when the circuit is assigned to a panel in the PANELS mode. These descriptions are just for program usage and should only be considered as such. In this phase, the user can add and delete series and attach or delete individual elements in the series after the system has been established.

In the second phase, the user can declare a new wire type to fit the project requirements. The program default will determine the wire size based on the size of the circuitry system. The user has the option of accepting the default or entering in a new wire size. When the user makes an alternate selection, the program will determine whether the new wire size is appropriate under the current circuitry system parameters. If the new wire size is not acceptable, the program will display a warning message and allow the user to either input another wire size or accept the original default.

PANELS Mode

The panels are a very important part in an electrical system. There are two primary types of panels: lighting and appliance panels, and power distribution panels. Lighting and appliance panels are used to control the power supplied to the lights, appliances, and receptacle outlets. The power distribution panels are used to control the allocation of power to various parts of a building via the lighting and appliance panels. The power distribution panels also regulate incoming voltage from the utility company and disperse this voltage throughout the facility.

The Panel Schedule command creates a table containing all the data on the panels in a project. The table includes the location of each panel, the amount of voltage into each panel, the number of circuits each panel is servicing, and the type of devices connected to the circuits of each panel. The information for each panel was originally input through the PANELS menu command mode.

The Circuit Summary report command gives the user a complete synopsis of the power system in a chart format. The engineer can tell the program which specific parts of the power system to include in the report through the Print Options command. The report is separated into four parts: receptacles, switches, panels, and branching. Any or all of these parts can be placed in the report at the user's discretion.

The Luminaire Summary report command gives the user luminaire information from the LITE program data base. The data includes all the values for calculating illuminance levels using the Illuminating Engineering Society (IES) Zonal Cavity Method.[9] This report is for informational purposes only, as the engineer must access the LITE program before changing the lighting layout.

PLOT Mode

The PLOT mode allows the user to receive a printed copy of the information on the screen. Depending upon the computer equipment at the user's facility, ECP can generate a file readable by a Calcomp plotter, or can transfer information on the screen to a plotter connected directly to the user's terminal. ECP has a command written specifically for the Tektronix 4692 color plotter which will erase the menu and redraw the screen in colors that are best suited to the plotter.

Common Modes

All of the modes grouped to the righthand side of the Menu Area are used for housekeeping type functions. PARAMETER EDIT allows the user to revise the parameters which control the operation of ECP. VIEWPORT EDIT controls which part of the viewport area will be seen on the screen. DISPLAY EDIT allows the user to see different dimensions relating to the building geometry. DRAW ROOMS redraws the screen in a double line drawing, while DRAW NETWORK redraws the screen in the single line depiction of the building. LEVEL EDIT allows the user to change levels or to list descriptive information for each level. SAVE PROJECT, NEXT PROJECT, and STOP perform the functions indicated by their command names.

No matter which command mode the user happens to be working in, there are five commands that can always be issued: They are Redraw (R), Zoomin (I), Zoomout (O), Back Up (<) and Stop (!).

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[9] C. Barton, *Development of LITE - A Graphic Module for Lighting Analysis in the Computer-Aided Engineering and Architectural Design System (CAEADS)*, Technical Report E-87/02 (USA-CERL, March 1987).

3 ECP/LITE INTERFACE

ECP is part of an interactive group of programs designed to enhance the concept design phase of engineering projects done by USACE engineers. The LITE program is used in lighting design and to calculate illuminance levels needed in facilities design. It allows the electrical engineer to layout the ceiling grid and place luminaires over the ARCH plan of the building. It also offers online IES Zonal Cavity calculations and the ability to create a Conservation of Electricity (CEL-1)* program input deck for daylighting analysis.[10]

ECP is designed to be used with the data base information stored in the LITE program to complete the concept design requirements for the electrical portion of the design package. The information is used by ECP to accurately include the lighting fixtures in the power system. Once ECP has been initiated, the user can retrieve information from the LITE program while in the IDENTIFY LUMINAIR mode. The only part of the data from the LITE program that is retained and stored in the ECP data base will be the actual X,Y,Z locations of the lighting fixtures. All other electrical data will be entered via ECP.

The interaction of LITE and ECP is minute but vital to the easy operation of the program and the success of the mechanical/electrical design package. ECP can be accessed without the interaction of LITE, but the layout process would be three to four times as long, and would defeat the purpose of the integrated approach. With this in mind, the user is encouraged to reference a data file from the LITE program before pursuing the circuitry design process using ECP.

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*CEL-1 is a daylighting analysis program developed by the Naval Civil Engineering Laboratory (NCEL) and the National Bureau of Standards (NBS).

[10]C. Barton, 1987.

4 ALGORITHMS

Voltage Drop Calculations

Voltage drop calculations are needed to ensure that enough voltage will be received by all equipment in the system. After establishing a one-line diagram, the user invokes the voltage drop calculations with the V command in the PANELS mode. Voltage drop in a circuit may be computed from the following formulas:[11]

Single-phase two-wire (and balanced single-phase three-wire) circuits:

$$V_d = \frac{2\ RIL}{c.m.} \qquad \text{[Eq 1]}$$

Balanced two-phase three-wire, three-phase three-wire, and balanced three-phase four-wire circuits:

$$V_d = \frac{3\ RIL}{c.m.} \qquad \text{[Eq 2]}$$

where V_d = voltage drop between any two-phase wires, or between phase wire and neutral when only one-phase wire is used in the circuit
I = current in amps
L = one way run in ft
R = resistance in ohms/mil-ft
c.m. = circular mils

The value of R (resistance in ohms to direct current of 1 mil-ft of wire) is assumed to be 10.7 for copper and 17.7 for aluminum. These equations will be the basis of the ECP voltage drop calculations, and will be applied to each section of the circuited system.

ECP will allow voltage drops used in design to range from 1 to 5 percent of the service voltage. Some codes set a maximum for voltage drop of 2.5 percent for combined light and power circuits from service entry to the building to the point of final distribution at branch panels. When this voltage drop is apportioned to the various parts of the circuit, it is 'economical' to assign the greater part, say 1.5 to 2 percent, to the smaller, more numerous feeders, and only 0.5 to 1 percent to the heavy main feeders between the service entry and main distribution panel.

ECP will prompt the user for the required voltage drop for each series being evaluated before calculating the actual voltage drop for the wire size indicated when creating the series. If the actual voltage drop is excessive, the program will use Equations 1 and 2 to calculate the required wire area, based on the desired voltage drop, and select the desired wire size using data from Table 20-4 of the *Building Design and Construction Handbook.*[12] For circuits designed for motor loads only, not lighting, the maximum voltage drop may be increased to a total of 5 percent. Of this, 1 percent can be assigned to branch circuits and 4 percent to feeders.

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[11] Charles J. Wurmfeld, "Electrical Power" (Section 20), *Building Design and Construction Handbook*, 4th Edition (McGraw-Hill, Inc., 1982), pp 20-28 and 20-29.
[12] Charles J. Wurmfeld.

Short Circuit Calculations

The ECP will use the "per-unit (pu)" method to calculate the fault currents in a power system. This method is standard practice in calculating short circuit currents for complex electrical systems. Before using these calculations, the user will have to know the base kilovoltamperes (kVA) which will be received from the buildings' power source.

After establishing a one-line diagram, the user invokes the short circuit calculations by using the T command in the PANELS mode. The calculations are adapted from the Institute of Electrical and Electronics Engineers, *IEEE Recommended Practices for Electric Power Systems in Commercial Buildings.*[13] Note that for the following equations, all ohmic values are single-phase distance one-way, which are later compensated for in the three-phase short circuit formula by the factor of (the square root of 3), as shown in Equation 9. Also note that the base kilovoltamperes used throughout will be 10,000 kVA.

$$\text{utility pu X} = \frac{\text{base kVA}}{\text{utility short-circuit kVA}} \qquad \text{[Eq 3]}$$

$$\text{transformer pu X} = \frac{(\%\text{X})(\text{base kVA})}{100\ (\text{transformer kVA})} \qquad \text{[Eq 4]}$$

where X = reactance

$$\text{transformer pu R} = \frac{(\%\text{R})(\text{base kVA})}{100\ (\text{transformer kVA})} \qquad \text{[Eq 5]}$$

$$\text{component pu x} = \frac{(\text{ohm X})(\text{base kVA})}{1000(\text{kV})^2} \qquad \text{[Eq 6]}$$

$$\text{component pu R} = \frac{(\text{ohm R})(\text{base kVA})}{1000(\text{kV})^2} \qquad \text{[Eq 7]}$$

After these equations have been computed, the pu X and pu R values are totaled for the system to the point of fault. Next the pu impedance total of the system is calculated with the following equation:

$$\text{pu } Z_T = (\text{pu } R_T)^2 + (\text{pu } X_T)^2 \qquad \text{[Eq 8]}$$

With that value, calculate the symmetrical root mean square (rms) short circuit current at the point of fault by:

$$I_{\text{sc sym rms}} = \frac{\text{base kVA}}{3\ (\text{kV})\ (\text{pu } Z_T)} \qquad \text{[Eq 9]}$$

[13]IEEE Standard 241-1974, *IEEE Recommended Practice for Electrical Power Systems in Commercial Buildings* (IEEE, 1974), pp 246-250.

To determine the motor load, add the full load motor currents. (Whenever the motor and lighting loads are considered, the generally accepted procedure is to assume 50 percent motor load based on the full-load current rating of the transformer.) The short circuit current that the motor load can contribute is an asymmetrical current usually approximated as being equal to the locked rotor current of the motors. As a close approximation with a margin of safety, the following equation will be used:

$$\text{Assym. Motor Contribution} = 5 \times \text{full-load motor current} \qquad \text{[Eq 10]}$$

A more exact determination depends upon the subtransient reactances of the motors in question and the associated circuit impedances. A less conservative method would involve the total motor circuit impedance to a common bus (sometimes referred to as a zero-reactance bus).

The symmetrical motor contribution can be approximated by using the average asymmetry factor associated with the motors in the system. This asymmetry factor varies according to motor design. ECP will use 1.25 as the asymmetrical factor for approximate calculation purposes in calculating the symmetrical motor contribution (SMC) as follows:

$$\text{SMC} = \frac{\text{asymmetrical motor contribution}}{\text{asymmetry factor}} \qquad \text{[Eq 11]}$$

The total symmetrical rms short circuit current is then calculated as:

$$\text{Total } I_{\text{sc sym rms}} = I_{\text{sc sym rms}} + \text{Symmetrical Motor Contribution} \qquad \text{[Eq 12]}$$

Note that arithmetic addition results in conservative values of fault current. More accurate values involve vectorial addition of the currents. The next step is to determine the X/R ratio of the system to the point of fault:

$$X/R = \frac{\text{pu } Xt}{\text{pu } Rt} \qquad \text{[Eq 13]}$$

where t = transformer

The ECP will have access to a table of asymmetrical factors, as shown in IEEE Standard 241-1974,[14] for determining the asymmetrical factor corresponding to the X/R ratio determined by Equation 13. This multiplier will provide the worst case asymmetry occurring in the first half-cycle. The table will also determine the average three-phase multiplier if desired. Then the asymmetrical rms short circuit current can be calculated as:

$$I_{\text{sc asym rms}} = I_{\text{sc sym rms}} \text{ X asymmetrical factor} \qquad \text{[Eq 14]}$$

Finally, the total asymmetrical rms short circuit current can be calculated as:

$$\text{Total } I_{\text{sc asym rms}} = I_{\text{sc asym rms}} + \text{asymmetrical motor contribution} \qquad \text{[Eq 15]}$$

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[14]IEEE Standard 241-1974.

Adding Wire Lengths

During the branching process of circuitry design, the wire being used has to be summed to determine the amount of wire needed to complete the project. The calculations included in ECP are designed to eliminate the time-consuming task of manually adding wire lengths. While in the PANELS mode, the engineer can calculate the wire length per series or the total wire length of the entire project by issuing the appropriate command. The engineer can quickly check circuits, redesign them for more efficient energy use, and recheck them. The algorithms for the calculations are as follows:

Individual Series Summation

$$\text{Total}_{WLS} = \sum_{n=1}^{\infty} nL \qquad \text{[Eq 16]}$$

where Total_{WLS} = total wire length for series (in ft)
n = number of element spaces in the series
L = length (in ft)

Total Wire Length for System

$$\text{Total}_{WL} = \sum_{n=1}^{\infty} n \ \text{Total}_{WLS} \qquad \text{[Eq 17]}$$

where Total_{WL} = total wire length for system (in ft)
n = series number.

Note that the program assumes that the wire in each series will be the same type.

5 SUMMARY

This report has documented the research and development effort of the proposed Electrical Circuitry Program. ECP has been developed by USA CERL to provide electrical engineers with automated tools to complete the electrical circuitry requirements during the concept design phase of a project.

ECP wou' 'ow the user to graphically place luminaire outlets (from interaction with the LITF am), receptacles, switches, and panel boards on the building plan. Although wirii .ms and voltage drop and short circuit calculations are not required for concept de .hese features were included to create a complete electrical circuitry program. ECP would produce reports and schedules giving the user vital information on variables used in the system design.

Initially, ECP was proposed as a single module in a set of interdisciplinary programs being developed at USA-CERL. However, the research effort behind these programs has been discontinued. Thus, while it is recommended that ECP be completed to aid in electrical circuitry analysis, research will not continue unless funding is allocated for this program.

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APPENDIX:

PC-BASED PROGRAMS REVIEWED

Calculation Programs

DAPPER - Distribution Analysis for Power Planning, Evaluation, and Reporting, by Control Data Corporation.

DAPPER is a system of computer programs for design specification and analysis of industrial, commercial, and institutional electrical power systems. The programs are capable of modeling multilevel voltage power systems containing one or more sources of fault contributions. Additionally, the programs can model any system configuration including radial design, loop design, and multiple isolated systems.

DAPPER does its calculations with vector analysis to be more precise in the solution of power system problems. The solutions are intended to meet the requirements of the NEC and incorporate data from sections of the NEC for design criteria. The programs are intended for use by engineers involved with design, specification, and maintenance of commercial, industrial, and institutional power systems. The solutions of DAPPER are for three-phase power systems normally found in these types of facilities.

SHORT CIRCUIT ANALYSIS by MC^2 Engineering Software

This program conducts fault current analysis with analytical methods based on the procedures outlined in *Engineering Dependable Protections for an Electrical Distribution System.**

SHORT CIRCUIT CALCULATIONS PROGRAM by Elite Software Development, Inc.

This program is based on the "per unit" method of calculations. Since the per unit method is a popular calculation method, any textbook or reference manual that explains the per unit method may be used as a reference. Resistance and reactance data for cables, bus ducts, circuit breakers, switches, and current transformers are taken from a variety of manufacturers such as Bussman, General Electric, and Federal Pacific. There is an option to define unique "X" (reactance) and "R" (resistance) data or revise current data found in the program.

VOLTAGE DROP CALCULATIONS PROGRAM by Elite Software Development, Inc.

This program performs "radial" voltage drop calculations for a given riser diagram. The riser diagram is defined in the form of a tree structured network. The electrical components of the riser diagram, such as cables, bus ducts, and transformers, are represented by segments in the network. These segments are defined through the input of two respective limiting modes. Each segment is completely described by component type, kVA load, and associated voltages. The voltage drop analysis is performed by segment paths extracted from the riser diagram. The results include the actual voltage drop at any given segment as well as the cumulative voltage drop at any point of the

*McGraw-Edison Company, Bussmann Manufacturing Division, "Part I: A Simple Approach to Short Circuit Calculations," *Engineering Dependable Protections for an Electrical Distribution System* (McGraw-Edison Co., 1968).

diagram. The Voltage Drop Calculations Program, features full screen editing, scrolling results, input data protection, and totally user-definable printed output reports. The program uses "X" and "R" values from predefined tables that may be edited by the program user.

SHORT CIRCUIT PROGRAM (Demonstration) by Electron International, Inc.

This program analyzes power system electrical performance under faulted conditions. Specifically, it will compute the voltages and currents in the power system immediately following any arbitrary fault or unbalance. The program quickly solves short circuit problems for medium sized power systems. It is written in a high-level optimizing language using sparse matrix techniques and efficient numerical methods to achieve its basic speed and solutions.

POWER FLOW PROGRAM (Demonstration) by Electron International, Inc.

This program assists in the layout and testing of a power system's reliability. The program has been written in a high-level optimizing language using sparse matrix techniques and efficient numerical methods to achieve its speed and solutions. The Power Flow Program can also be redimensioned to handle any size power flow case up to 2,500 buses and 5,400 branches.

Graphics Programs

ELECTRICAL POWER/LIGHTING by Intergraph Corporation.

This program is included in Intergraph's CAD (Computer-Aided Design) program, where the engineer can layout a circuited power system on the floor plan input by the architects without having to change computers or programs. It is primarily a graphic program and contains various menus to assist the engineer in scaling a power system. Branch Panels, Reports, Circuit Manipulation, Ceiling Grid, and Circuit Design are menus included in the program. It will satisfactorily draw a complete system. Electrical Power/Lighting is strictly a drawing program and will not do calculations.

ONE-LINE DIAGRAM PROGRAM (Demonstration) by Electron International, Inc.

This program is a tool for computerized construction, modification, and display of one-line diagrams of electrical power systems. The user may lay out, inspect, and modify diagrams using a suitable graphics display on a personal computer, and obtain hard copies on a dot matrix printer or other hard copy device. Once a system diagram has been constructed, it can be used to present numeric results from any subsequent run of the Power Flow Program in a clear visual format.

WIREMAP PROGRAM (Demonstration) by Dynacomp, Inc.

This program generates wiring data lists which can be used in developing, producing, troubleshooting, and documenting electric circuits. Once the circuit data has been fed into the program and saved, several types of output may be quickly and easily generated by the program whenever needed, thus cutting down on the time spent by engineers, technicians, and others to organize and collate circuit data.

Wiremap requires that each component in a circuit be assigned a name, a component designator, and pin numbers. Further, each pin is required to have a signal name associated with it, which translates into each individual signal path in the circuit regarding a unique signal name. The program also has a number of "LIST" parameters that give the various information required for a report: Signal List, Wire List, Parts List, and Data List. The Signal List gives all components and pins to which each signal in the circuit is tied. The Wire List gives the destinations of every pin of every component in the circuit on a pin-by-pin basis for each component in the circuit. The Parts List gives the name, component designator, and number of pins of all components used in the circuit. The Data List shows all circuit data as originally entered and lists component name, component designator, and signal name at each pin for each component in the circuit.

LADDER PROGRAM (Demonstration) by Dynacomp, Inc.

This program uses the technique of describing a network as a series of cascaded two-ports. This representation is sometimes pictured as a "ladder." Each two-port is described individually, from load to source, in a data file generated by following the program prompts. Each element type and value is then read and an "ABCD" matrix for each element is generated. This matrix describes the transfer characteristics of the two-port element and the multiplication of two or more "ABCD" matrices will yield the total transfer characteristics of the series of two-ports. Ladder uses matrices (with complex numbers) to describe the transfer characteristics of passive networks, such as capacitors, resistors, inductors, and transmission lines. The network architectures may include parallel and series branches to any depth, open and shorted stubs, and two parallel or series ladder networks. All elements, except resistors, require that a quality factor or loss figure be defined at a single, operator defined, frequency. With this information, the network responses are determined using "real world" components. This program can handle networks consisting of up to 50 two-port elements.

Design Systems Team Distribution

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ATTN: Tech Monitor
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ATTN: CEEC-M (2)
ATTN: CEEC-ZA
ATTN: DAEN-ZCP

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ATTN: Chief, Engr Division
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